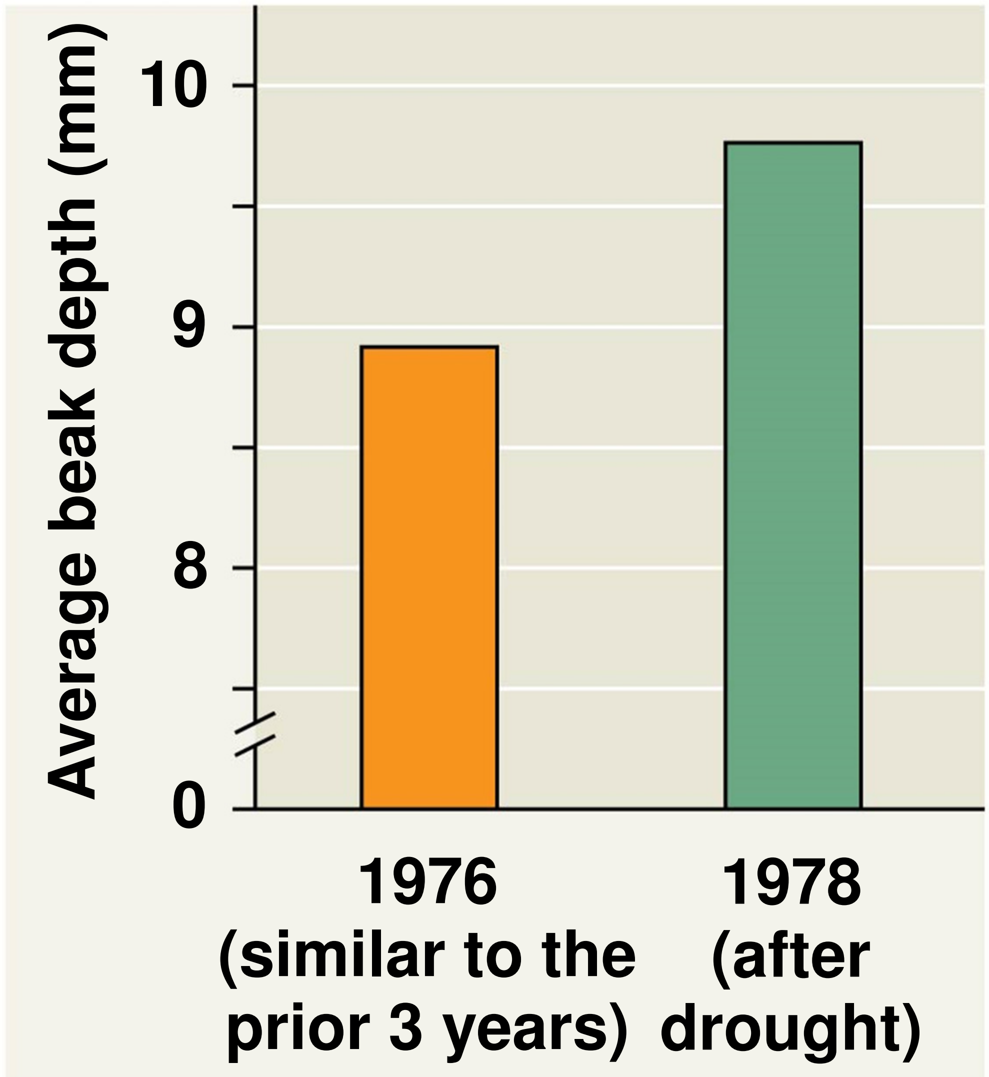
Unit 7
Evolution

Chapter 21: The Evolution of Populations

Overview: The Smallest Unit of Evolution

- One common misconception is that organisms evolve during their lifetimes
- Natural selection acts on individuals, but only populations evolve over time
- Consider, for example, a population of medium ground finches on Daphne Major Island
  - During a drought, large-beaked birds were more likely to crack large seeds and survive
  - The finch population evolved by natural selection

Figure 21.2


Average beak depth (mm)
10
9
8
0
1976
(similar to the
prior 3 years)
1978
(after
drought)

- **Microevolution** is a change in allele frequencies in a population over generations
- Three mechanisms cause allele frequency change
  1. Natural selection
     - Eliminates members of a population that are least adapted
  2. Genetic drift
     - Chance events that alter allele frequencies
  3. Gene flow
     - Transfer of alleles between populations
- Only natural selection causes adaptive evolution

Concept 21.1: Genetic variation makes evolution possible

- Variation in heritable traits is a prerequisite for evolution
- Mendel's work on pea plants provided evidence of discrete heritable units (genes)
- Phenotypic variation often reflects **genetic variation**
  - Differences among individuals in the composition of their genes or other DNA sequences

- Some phenotypic differences are due to differences in a single gene and can be classified on an "either-or" basis
  - Ex: Purple or white flowers
- Other phenotypic differences are due to the influence of many genes and vary in gradations along a continuum
  - Ex: Coat color in horses, height in humans
- Phenotype is the product of inherited genotype and environmental influences
- Natural selection can only act on phenotypic variation that has a genetic component
- Without genetic variation, evolution cannot occur

Sources of Genetic Variation

- New genes and alleles can arise by mutation or gene duplication

Formation of New Alleles

- A *mutation* is a change in the nucleotide sequence of DNA
- Only mutations in cells that produce gametes can be passed to offspring
- The effects of point mutations can vary
  - Mutations in noncoding regions of DNA are often harmless
  - Mutations to genes can be neutral because of redundancy in the genetic code
  - Mutations that alter the phenotype are often harmful
  - Mutations that result in a change in protein production can sometimes be beneficial

Altering Gene Number or Position

- Chromosomal mutations that delete, disrupt, or rearrange many loci are typically harmful
- A key potential source of variation is the duplication of genes due to
  - Errors in meiosis
    - Unequal crossing over
  - Slippage during DNA replication
  - Activities of transposable elements
- Duplication of small pieces of DNA increases genome size and is usually less harmful
  - Duplicated genes can take on new functions by further mutation

Rapid Reproduction

- Mutation rates are low in animals and plants
  - The average is about one mutation in every 100,000 genes per generation
- Mutation rates are often lower in prokaryotes and higher in viruses
- Short generation times allow mutations to accumulate rapidly in prokaryotes and viruses

Sexual Reproduction

- In organisms that reproduce sexually, most genetic variation results from recombination of alleles
- Sexual reproduction can shuffle existing alleles into new combinations through three mechanisms:
  - Crossing over
  - Independent assortment
  - Fertilization

Concept 21.2: The Hardy-Weinberg equation can be used to test whether a population is evolving

- The presence of genetic variation does not guarantee that a population will evolve
- A **population** is a localized group of individuals capable of interbreeding and producing fertile offspring

Gene Pools and Allele Frequencies

- A **gene pool** consists of all the alleles for all loci in a population
- An allele for a particular locus is fixed if all individuals in a population are homozygous for the same allele

- The frequency of an allele in a population can be calculated
  - For diploid organisms, the total number of alleles at a locus is the total number of individuals times 2
  - The total number of dominant alleles at a locus is 2 alleles for each homozygous dominant individual plus 1 allele for each heterozygous individual
    - The same logic applies for recessive alleles

- By convention, if there are 2 alleles at a locus, p and q are used to represent their frequencies
- The frequency of all alleles in a population will add up to 1
  - For example, $p + q = 1$

- For example, consider a population of wildflowers that is incompletely dominant for color
  - 320 red flowers (C^RC^R)
  - 160 pink flowers (C^RC^W)
  - 20 white flowers (C^WC^W)
- Calculate the number of copies of each allele
  - $C^R = (320 \times 2) + 160 = 800$
  - $C^W = (20 \times 2) + 160 = 200$

- To calculate the frequency of each allele
  - p = freq C^R = 800 / (800 + 200) = 0.8 (80%)
  - q = freq C^W = 200 / (200 + 800) = 0.2 (20%)
- The sum of alleles is always 1
  - 0.8 + 0.2 = 1

The Hardy-Weinberg Principle

- The Hardy-Weinberg principle describes a population that is not evolving
- If a population does not meet the criteria of the Hardy-Weinberg principle, it can be concluded that the population is evolving

Hardy-Weinberg Equilibrium

- The **Hardy-Weinberg principle** states that frequencies of alleles and genotypes in a population remain constant from generation to generation
  - Provided only Mendelian segregation and recombination of alleles are at work
- In a given population where gametes contribute to the next generation randomly, allele frequencies will not change
- Mendelian inheritance preserves genetic variation in a population

- Hardy-Weinberg equilibrium describes the constant frequency of alleles in such a gene pool
- Consider, for example, the same population of 500 wildflowers and 1,000 alleles where
  - $p = \text{freq } C^R = 0.8$
  - $q = \text{freq } C^W = 0.2$

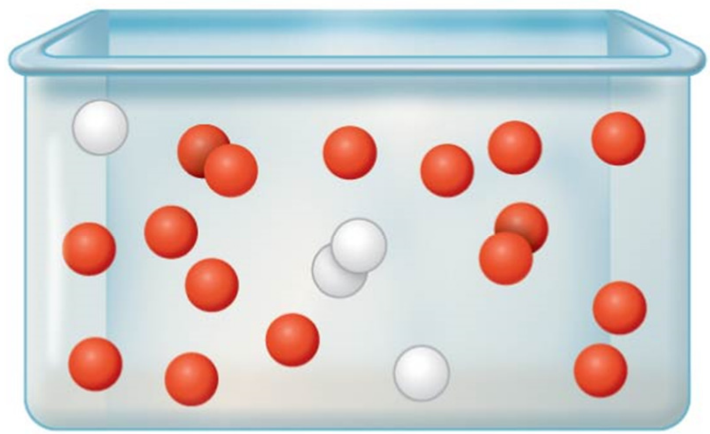
Figure 21.7

Frequencies of alleles

p = frequency of C^R allele = 0.8

q = frequency of C^W allele = 0.2

Alleles in the population



Gametes produced

Each egg:

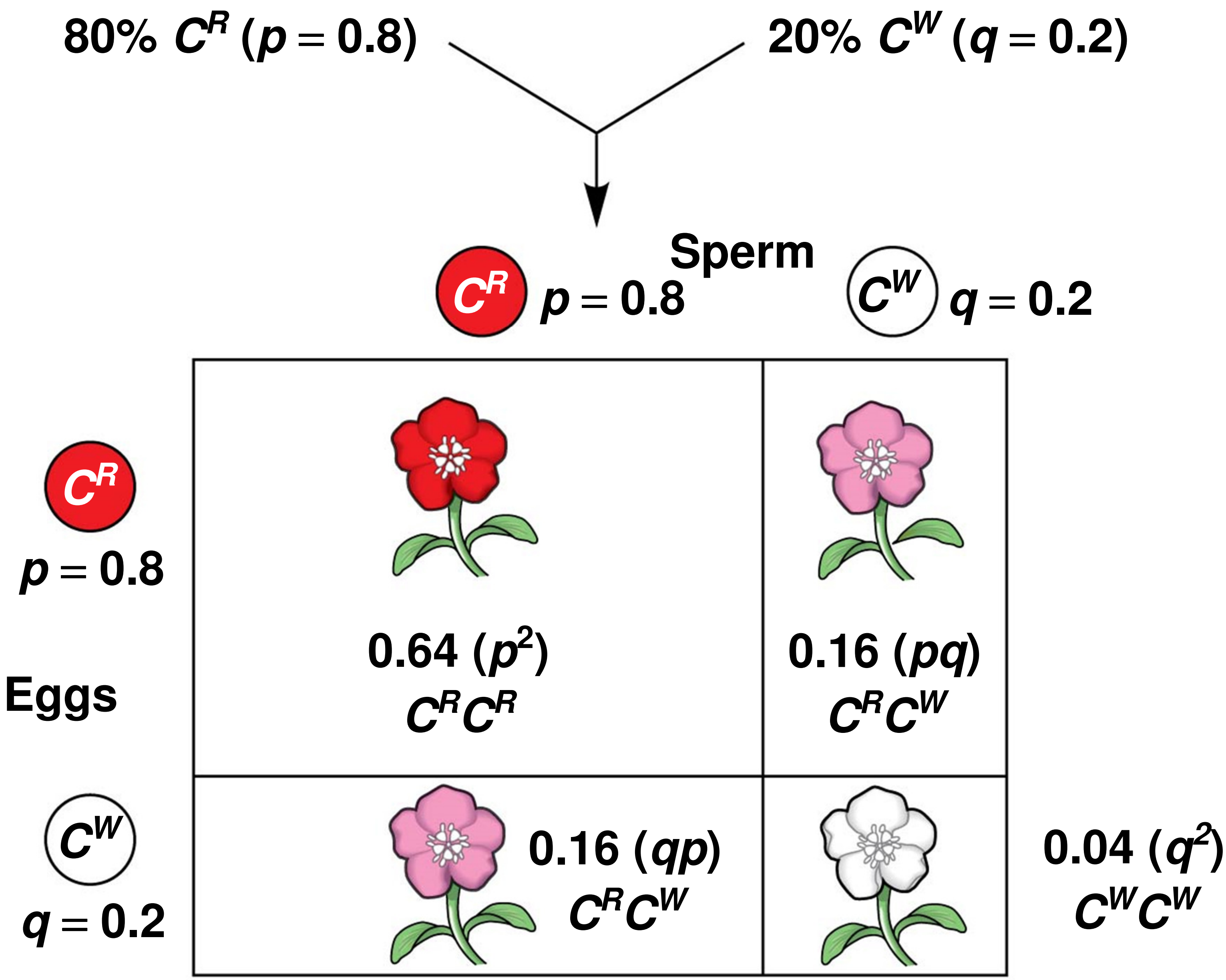
80% chance | 20% chance

Each sperm:

80% chance | 20% chance

- The frequency of genotypes can be calculated
  - $C^RC^R = p^2 = (0.8)^2 = 0.64$
  - $C^RC^W = 2pq = 2(0.8)(0.2) = 0.32$
  - $C^WC^W = q^2 = (0.2)^2 = 0.04$
- The frequency of genotypes can be confirmed using a Punnett square

Figure 21.8a



80% C^R ($p = 0.8$)
20% C^W ($q = 0.2$)
Sperm
C^R $p = 0.8$
C^W $q = 0.2$
Eggs
C^R $p = 0.8$
C^W $q = 0.2$
0.64 (p^2) C^RC^R
0.16 (pq) C^RC^W
0.16 (qp) C^RC^W
0.04 (q^2) C^WC^W

Figure 21.8b

64% C^RC^R, 32% C^RC^W, and 4% C^WC^W

↓

Gametes of this generation:

64% C^R (from C^RC^R plants) + 16% C^R (from C^RC^W plants) = 80% $C^R = 0.8 = p$

4% C^W (from C^WC^W plants) + 16% C^W (from C^RC^W plants) = 20% $C^W = 0.2 = q$

With random mating, these gametes will result in the same mix of genotypes in the next generation:

↓

64% C^RC^R, 32% C^RC^W, and 4% C^WC^W plants

$$p^2 + 2pq + q^2 = 1 \quad \text{and} \quad p + q = 1$$

- p represents the relative frequency of the dominant allele
- q represents the relative frequency of the recessive allele

- p^2 represents the frequency of the homozygous dominant genotype
- q^2 represents the frequency of the homozygous receissive genotype
- $2pq$ represents the frequency of the heterozygous genotype

Conditions for Hardy-Weinberg Equilibrium

- The Hardy-Weinberg theorem describes a hypothetical population that is not evolving
- In real populations, allele and genotype frequencies do change over time

- The five conditions for nonevolving populations are rarely met in nature
  1. No mutations
  2. Random mating
  3. No natural selection
  4. Extremely large population size
  5. No gene flow
- Departure from these conditions usually results in evolutionary change

Applying the Hardy-Weinberg Principle

- Hardy-Weinberg equation is often used as an initial test of whether evolution is occurring in a population
- Also has medical applications
  - Estimating the percentage of a population carrying the allele for an inherited disease

- We can assume the locus that causes phenylketonuria (PKU) is in Hardy-Weinberg equilibrium given that
  1. The PKU gene mutation rate is low
  2. Mate selection is random with respect to whether or not an individual is a carrier for the PKU allele
  3. Natural selection can only act on rare homozygous individuals who do not follow dietary restrictions
  4. The population is large
  5. Migration has no effect, as many other populations have similar allele frequencies

- The occurrence of PKU is 1 per 10,000 births
  - $q^2 = 0.0001$
  - $q = 0.01$
- The frequency of normal alleles is
  - $p = 1 - q = 1 - 0.01 = 0.99$
- The frequency of carriers is
  - $2pq = 2 \times 0.99 \times 0.01 = 0.0198$
  - or approximately 2% of the U.S. population

Concept 21.3: Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- Three major factors alter allele frequencies and bring about most evolutionary change
  1. Natural selection
  2. Genetic drift
  3. Gene flow

Natural Selection

- Differential success in survival and reproduction results in certain alleles being passed to the next generation in greater proportions
  - Individuals with traits that are better suited to the environment tend to produce more offspring than those with traits not as well suited
- Natural selection can cause *adaptive evolution*
  - Results in better match between organisms and their environment

Genetic Drift

- The smaller a sample, the more likely it is that chance alone will cause deviation from a predicted result
- **Genetic drift** describes how allele frequencies fluctuate unpredictably from one generation to the next due to chance events
  - Especially in small populations
- Genetic drift tends to reduce genetic variation through losses of alleles
- Two examples of how genetic drift can have a significant impact on a population are
  - The founder effect
  - The bottleneck effect

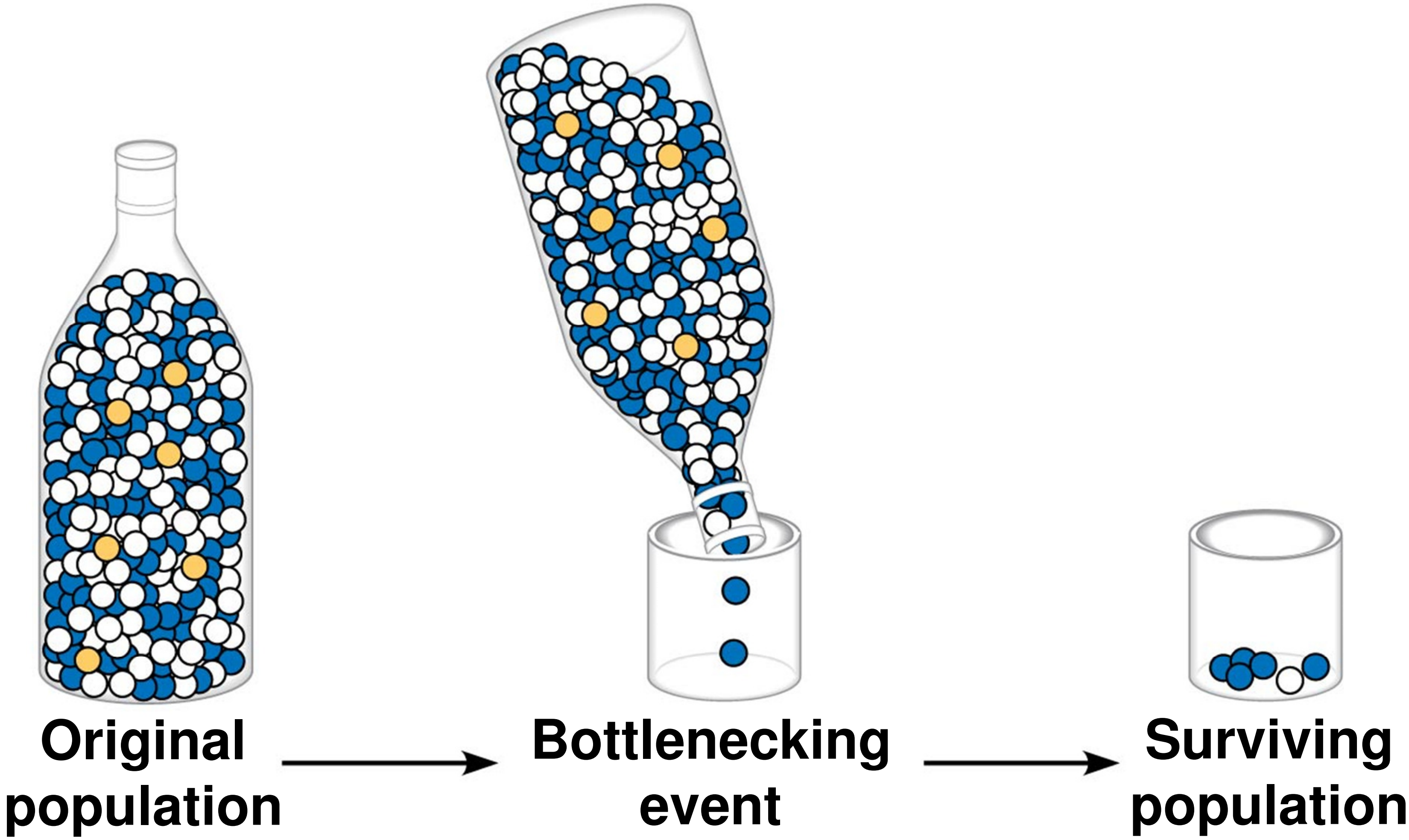
The Founder Effect

- The **founder effect** occurs when a <u>few</u> individuals become <u>isolated</u> from a larger population
  - Smaller group may establish a new population whose gene pool differs from the source population
- Allele frequencies in the small founder population can be different from those in the larger parent population due to <u>chance</u>
- Ex: A few members of a population are blown by a storm to a new island

The Bottleneck Effect

- The **bottleneck effect** can result from a drastic reduction in population size due to a sudden environmental change
- By chance, the resulting gene pool may no longer be reflective of the original population’s gene pool
- If the population remains small, it may be further affected by genetic drift
- Understanding the bottleneck effect can increase understanding of how human activity affects other species

Figure 21.10a-3



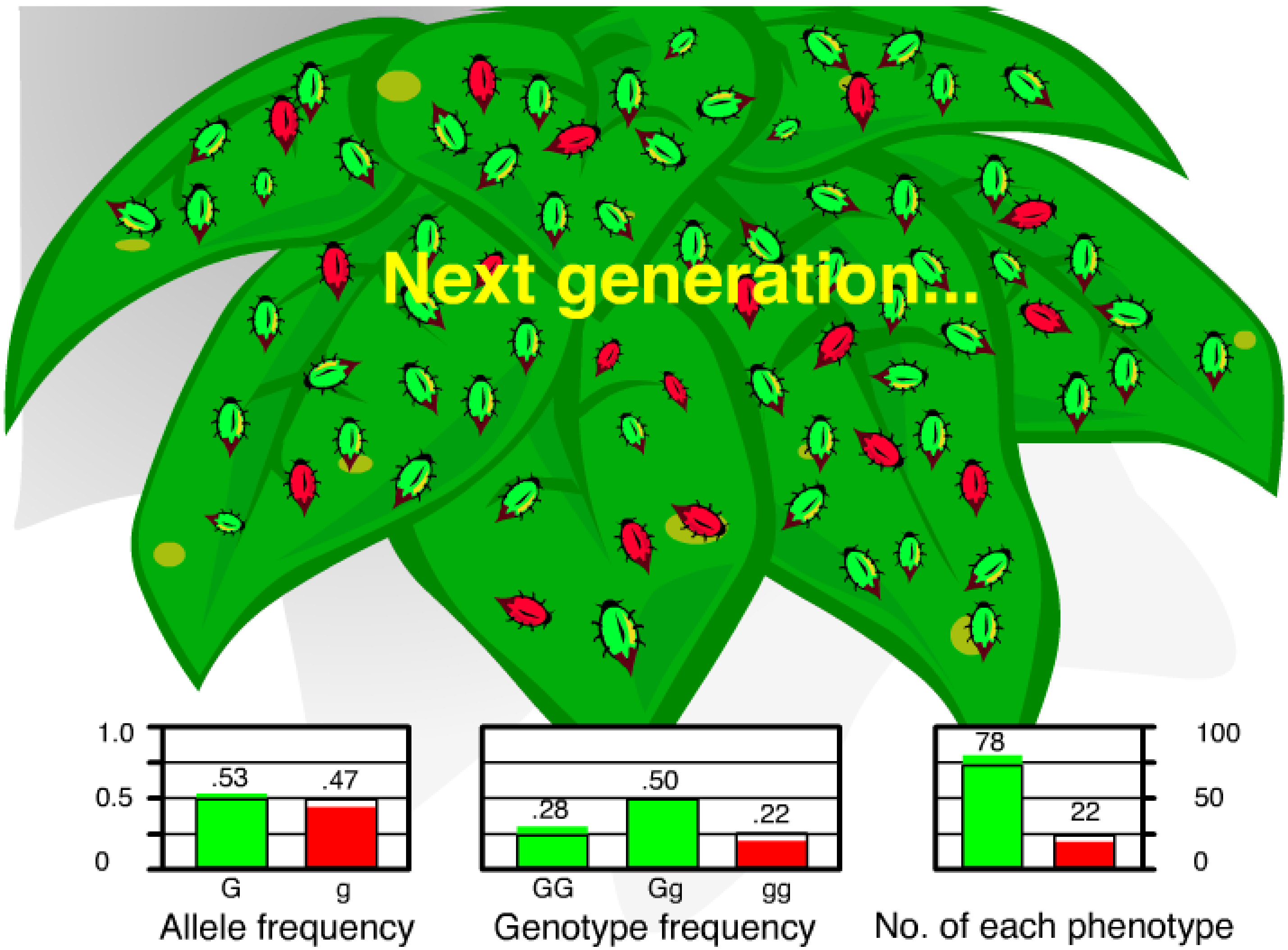
(a) By chance, blue marbles are overrepresented in the surviving population.

Effects of Genetic Drift: A Summary

1. Genetic drift is significant in small populations
2. Genetic drift can cause allele frequencies to change at random
3. Genetic drift can lead to a loss of genetic variation within populations
4. Genetic drift can cause harmful alleles to become fixed

Gene Flow

- **Gene flow** consists of the movement of alleles among populations
- Alleles can be transferred through the movement of fertile individuals or gametes (for example, pollen)
- Gene flow tends to <u>reduce genetic variation</u> among populations over time
  - Can result in two populations combining into a single population with a common gene pool
- Gene flow can increase or decrease the fitness of a population
- Gene flow is an important agent of evolutionary change in modern human populations



Animation: Causes of Evolutionary Changes
Right click slide / Select play

Concept 21.4: Natural selection is the only mechanism that consistently causes adaptive evolution

- Evolution by natural selection involves both chance and “sorting”
  - New genetic variations arise by chance
  - Beneficial alleles are “sorted” and favored by natural selection
- Only natural selection consistently results in **adaptive evolution**
  - An increase in the frequency of alleles that improve fitness

Natural Selection: *A Closer Look*

- Natural selection brings about adaptive evolution by acting on an organism's phenotype
- **Relative fitness** is the contribution an individual makes to the gene pool of the next generation, relative to the contributions of other individuals
- Selection indirectly favors certain genotypes by acting directly on phenotypes!

Directional, Disruptive, and Stabilizing Selection

- There are three modes of natural selection

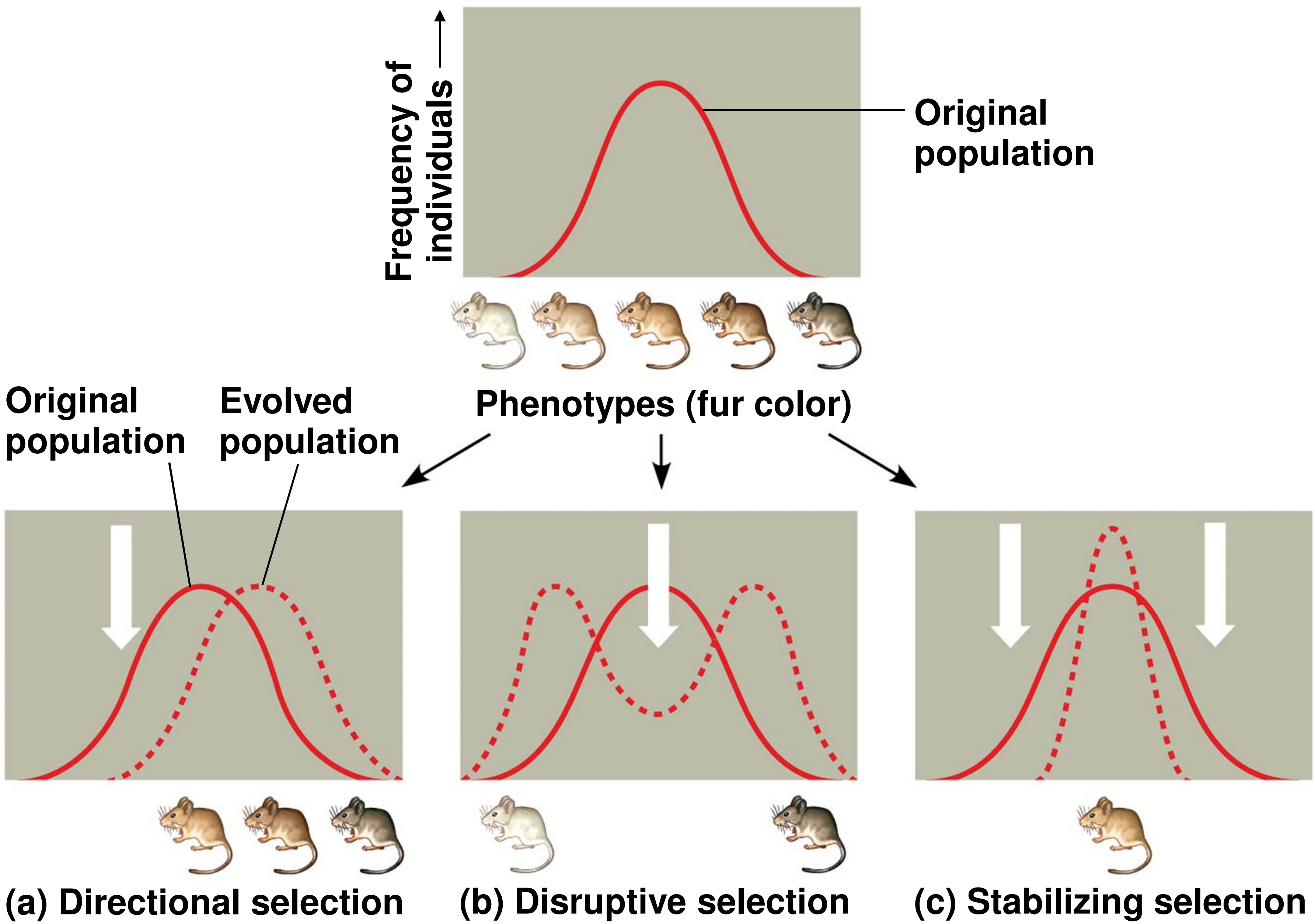
1. **Directional selection** favors individuals at one extreme of the phenotypic range
    - Shifts a population's frequency curve in one direction or the other
    - Common when a population's environment changes or migration occurs

2. **Disruptive selection** favors individuals at both extremes of the phenotypic range

3. **Stabilizing selection** favors intermediate variants and acts against extreme phenotypes
   - Reduces variation
   - Ex: Birth weights of most human babies are between 6.6 and 8.8 lbs

- Regardless of the mode of selection, the basic mechanism remains the same
  - Selection favors individuals whose heritable traits provide higher reproductive success

Figure 21.13


Frequency of individuals
Original population
Phenotypes (fur color)
Original population
Evolved population
(a) Directional selection
(b) Disruptive selection
(c) Stabilizing selection

The Key Role of Natural Selection in Adaptive Evolution

- Striking adaptations have arisen by natural selection
  - Certain octopuses can change color rapidly for camouflage
  - Jaws of snakes allow them to swallow prey larger than their heads

- Natural selection increases the frequencies of alleles that enhance survival and reproduction
- Adaptive evolution occurs as the match between an organism and its environment increases
- Because the environment can change, adaptive evolution is a continuous, dynamic process
- Genetic drift and gene flow do not consistently lead to adaptive evolution
  - They can increase or decrease the match between an organism and its environment
- Natural selection is the only evolutionary mechanism that consistently leads to adaptive evolution!

Sexual Selection

- **Sexual selection** is a form of natural selection in which individuals with certain inherited characteristics are more likely than others to obtain mates
- It can result in **sexual dimorphism**
  - Marked differences between the sexes in secondary sexual characteristics

- *Intrasexual selection* is competition among individuals of one sex (often males) for mates of the opposite sex
- *Intersexual selection*, often called mate choice, occurs when individuals of one sex (usually females) are choosy in selecting their mates
  - Male showiness due to mate choice can pose some risk
  - May increase a male’s chances of attracting a female, while decreasing his chances of survival
    - Ex: Bright feathers may make male birds more visible to predators

The Preservation of Genetic Variation

- **Neutral variation** is genetic variation that does not confer a selective advantage or disadvantage
- Various mechanisms help to preserve genetic variation in a population
  - Diploidy
  - Balancing selection

Diploidy

- Diploidy maintains genetic variation in the form of hidden recessive alleles
- Heterozygotes can carry recessive alleles that are hidden from the effects of selection

Balancing Selection

- **Balancing selection** occurs when natural selection maintains stable frequencies of two or more phenotypic forms in a population
- Balancing selection includes
  - Heterozygote advantage
  - Frequency-dependent selection

- **Heterozygote advantage** occurs when heterozygotes have a higher fitness than do both homozygotes
  - Defined in terms of genotype, not phenotype
- Natural selection will tend to maintain two or more alleles at that locus
- For example, the sickle-cell allele causes deleterious mutations in hemoglobin but also confers malaria resistance

- In **frequency-dependent selection**, the fitness of a phenotype depends on how common it is in the population
  - Selection can favor whichever phenotype is less common in a population

Why Natural Selection Cannot Fashion Perfect Organisms

1. Selection can act only on existing variations
2. Evolution is limited by historical constraints
3. Adaptations are often compromises
   - Ex: Structural reinforcement compromised for agility
   - Ex: Call or colors attract mates AND predators
4. Chance, natural selection, and the environment interact